RR LYRAE VARIABLES IN THE GLOBULAR CLUSTERS OF M31: A FIRST DETECTION OF LIKELY CANDIDATES[1]

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ABSTRACT

The purpose of this paper is to show that RR Lyrae variables exist and can be detected in M31 globular clusters. We report on the first tentative identification of RR Lyrae candidates in four globular clusters of the Andromeda galaxy, i.e. G11, G33, G64 and G322. Based on HST-WFPC2 archive observations in the F555W and F814W filters spanning a total interval of about 5 consecutive hours we find evidence for 2, 4, 11 and 8 RR Lyrae variables of both *ab* and *c* Bailey types in G11, G33, G64 and G322, respectively. Several more candidates can be found by relaxing slightly the selection criteria. These numbers are quite consistent with the horizontal branch morphology exhibited by the four clusters, starting from the very blue HB in G11, and progressively moving to redder HBs in G64, G33 and G322.

Subject headings: Galaxies: individual (M31) – galaxies: stellar content – galaxies: star clusters — Local Group — stars: variables: other

1. INTRODUCTION

RR Lyraes are the most common class of intrinsic variable stars in the Galaxy and in the Local Group. Their almost constant average absolute magnitude makes them primary distance indicators in the Galaxy and in the Magellanic Clouds, hence they are cornerstones of cosmological distance and time scales.

Evidence for the presence of RR Lyrae variables has been found in almost all of the Local Group galaxies where a search has been pushed deep enough to reach the horizontal branch (HB). M31 is no exception to this general rule. However, very few RR Lyrae variables have been identified so far in this galaxy. Pritchet & van den Bergh (1987) found 30 probable field RR Lyraes with the CFH 3.6-m telescope in conditions of "excellent" seeing. Difference imaging of M31 has also revealed some possible field RR Lyraes (Sugerman, Uglesich & Crotts, 1999). The faintness of the targets and the severe crowding conditions have prevented any further search for RR Lyraes in that galaxy. Nevertheless, the estimated relative frequency of such variables indicates that a very rich harvest of them should be present in the stellar spheroid of M31 (Pritchet & van den Bergh, 1987). As for RR Lyraes in M31 globular clusters, no observation has been attempted from the ground because the high spatial resolution provided so far only by the HST is mandatory to resolve these stars.

Identification of the RR Lyrae population in the globular clusters of M31, however, can provide fundamental insights on the distance scale, the stellar content, and the formation process of M31, since a globular cluster stellar population has the advantage over the field of being homogeneous in age and metallicity.

The pulsational properties of RR Lyrae stars are known well enough to help in understanding several important questions: (i) What is the Population II distance to M31 and how does it compare to the distance derived from Population I indicators, Cepheids in particular? (ii) What is the relation between the M31 halo and its globular clusters, and how do the cluster characteristics compare with their counterparts in the Milky Way? (iii) What are the stellar content and the metallicity of the M31 spheroid?

Item (i) is particularly important as a fundamental step to strengthen the calibration of the distance scale, hence the determination of the time scale and all related cosmological parameters. In fact, thanks to its large distance any projection and/or line of sight depth effects are much less important in M31 than in nearer Local Group systems, such as the Magellanic Clouds. Moreover, an Sb I-II giant spiral galaxy provides a much more appropriate local counterpart to the Distance Scale Key Project galaxies than does the LMC (see reviews by Freedman (2000) and Tammann (2000) and references therein). Therefore, in any respect except for ease of observations, M31 is a much more

[1]Based on observations made with the NASA/ESA Hubble Space Telescope, obtained from the data archive at the Space Telescope Science Institute. STScI is operated by the Association of Universities for Research in Astronomy, Inc. under NASA contract NAS 5-26555.

appropriate cornerstone for the distance scale than the LMC.

Item (ii) directly bears upon the halo formation processes in M31. Almost all Galactic globular clusters which contain significant numbers of RR Lyrae stars can be placed into Oosterhoff groups I and II (Oosterhoff 1939) on the basis of the mean periods and relative proportions of their RRab and RRc stars. That is not true for all globular clusters, e.g. those of the LMC, which can have properties intermediate between the two Oosterhoff groups (Bono, Caputo & Stellingwerf, 1994). It has been suggested that Milky Way globulars belonging to different Oosterhoff groups may represent the products of different accretion/formation events in the halo (e.g. van den Bergh 1993). The existence or absence of the Oosterhoff phenomenon among the M31 globular clusters may therefore provide an additional constraint on the similarity of halo formation processes in the two systems. Finally, a direct comparison of the properties of variables in globular clusters and in the adjacent fields would provide a very interesting diagnostic as to whether the spheroid and the globular cluster system share a common origin.

In this letter we report on the first tentative identification of RR Lyrae variable candidates in four globular clusters observed with the HST, namely G11, G33, G64 and G322 (Sargent et al. 1977). A larger number of candidate variable objects of unclassified type has also been found.

2. MINING THE HST DATA ARCHIVE ON THE GLOBULAR CLUSTERS OF M31

The globular cluster population of the Andromeda galaxy has been the subject of a number of HST programs. HST color magnitude diagrams (CMDs) reaching one magnitude below the HB level are presently available for 19 of the M31 globulars (Ajhar et al. 1996; Rich et al. 1996; Fusi Pecci et al. 1996; Holland, Fahlman & Richer 1997; Corsi et al. 2000; Rich et al. 2001). Among these clusters we have selected those with: a) well defined CMDs and populous enough HBs; and b) a large enough number (n$\geq$4) of suitably long individual exposures (in each passband) so that a variability search could be performed on the basis of the scatter of the individual photometric measures with respect to the average value.

Four clusters satisfy the above requirements, namely G11, G33, G64 and G322 (see Table 1). All of them are metal poor or of intermediate metallicity, thus by analogy to the Galactic clusters we may expect they contain RR Lyrae stars. Indeed, at [Fe/H] $\leq$ –1.7, G11, G33 and G64 are the sort of clusters which in the Milky Way would likely belong to OoII. G322 is of intermediate metallicity, similar to clusters which would likely be OoI systems in the Milky Way.

The positions of the four clusters with respect to the nucleus of M31 are shown in Figure 1, and projected distances from the M31 center are given in column 3 of Table 1.

TABLE 1. Information on the four selected clusters

Id.	V (int.)	r (′)	E(B–V) (mag)	[Fe/H] (spectr.)
G11	16.36	75.75	0.10	–1.89
G33	15.48	57.59	0.22	–1.74
G64	15.08	25.35	0.17	–1.81
G322	15.61	61.80	0.10	–1.21

NOTE. - Adopted values of reddening are from Frogel et al. (1980); metallicities are from Huchra et al. (1991), positions with respect to the center of M31 and integrated luminosities are from Corsi et al. (2000).

Four F555W (V) and four F814W (I) frames taken with the HST PC (GO program 6671, PI R.M. Rich) are available for each of the selected clusters. For each cluster, individual exposures are 20 minutes long and consecutive observations cover a total time interval of 5h 15m, with the first 2-hr block devoted to V and the remaining time to I. These integration times are adequate for our purposes, as they are long enough to give an r.m.s. error of $\sim$ 0.10 mag on the *individual* measures at the HB level, and yet short enough to avoid blurring of the light curves.

3. ANALYSIS OF THE PHOTOMETRIC DATA: VARIABLE SEARCH

The F555W and F814W frames retrieved from the HST archive for the selected clusters were reduced individually using the ROMAFOT reduction package, which is especially optimized for accurate photometry in crowded fields (Buonanno et al. 1983).

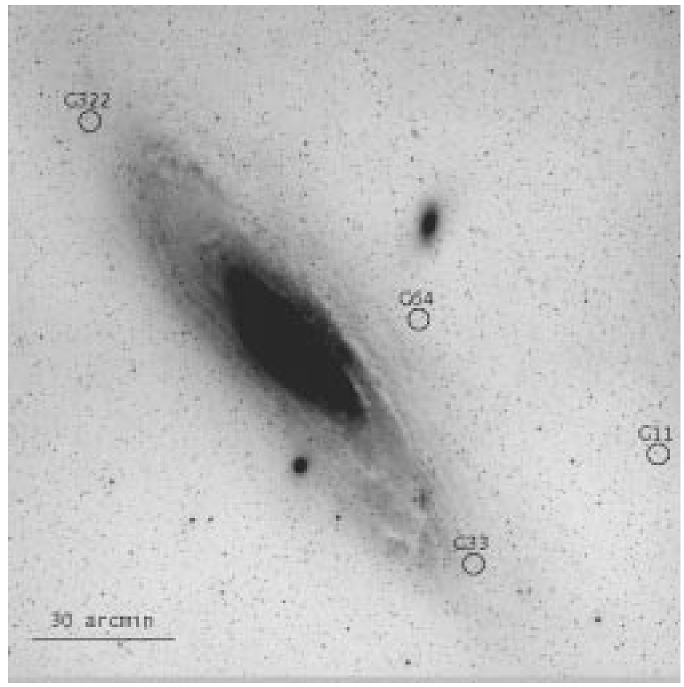

FIG. 1. Location of G11, G33, G64 and G322 with respect to M31 main body.

We have adopted the following criteria for identifying RR Lyrae-like candidates:

i) average luminosity of the available data points within $\pm$ 1 mag of the HB average magnitude level at the color of the instability strip. No restriction was put on the stellar color, however, because the $<V>-<I>$ colors of variable objects are artificially distorted by phase mismatch of the V and I data that were taken sequentially and not simultaneously. As a matter of fact, given the time baseline of the data only variables with periods shorter than about 2-3 hours have a full coverage in phase in each passband, so that the average values of the present data would actually correspond to their average magnitudes and colors. Vice versa, variables of longer periods may well fall outside the boundaries on either side of the instability strip.

ii) We considered objects with no less than 3 measurements in each of the two photometric passbands, and r.m.s. deviations larger than 0.3 mag., i.e. 3σ from the average r.m.s. value, in at least one passband. This search was performed on the F555W and F814W frames independently.

The sequences of individual measurements were then displayed as a function of the Julian Day of observation, searching for trends, shapes and possible periodicities in the light variations which were compatible with RR Lyrae type variations.

It should be remembered that given the short time coverage of the archival data a strong bias exists against the detection of variables with periods longer than $\sim$ 5 hours. Thus the only *ab*-type variables which can be detected from the present data are those caught during the rapid rise to maximum light or the upper part of the descending branch in at least one of the two photometric bands. On the other hand, detection of the *c*-type variables, while favoured by the shorter periods, is made difficult by the smaller amplitude of their light variations.

iii) The final and decisive criterion was a check that the detected indication of variability was indeed consistent with real RR Lyrae light curves in the V and I bands. To this purpose we have considered a grid of V and I light curves of RR Lyraes from the globular cluster M3 ([Fe/H]~ -1.5 and E(B–V)=0.0, Carretta et al. 1998) sampling 4 c-type variables with periods in the range 0.29-0.49 d, and 15 ab-type variables with periods in the range 0.46-0.66 d. These template light curves were transferred into the V,I vs. JD plane using their periods, were reddened (A_V=3.1E(B–V) and A_I=1.9E(B–V) - Schlegel et al. 1998) using the appropriate reddening value for each M31 cluster (see Table 1), and were converted into HST magnitudes using the relations of Holtzman et al. (1995). A comparison could then be performed directly in the HST photometric system with the V,I data of the selected candidate variable stars: rigid shifts (i.e. the same value for the V and I data) were applied vertically (because of the different apparent magnitude of stars and templates) and horizontally to each star in search of the best match of the individual V and I data sets with the most suitable template. These shifts of course vary from star to star, because they depend on the (unknown) phases and magnitudes at which the stars were observed. The stars we eventually selected as likely RR Lyrae candidates are those for which at least 3 data points per color fall on the respective template light curve within 0.1 mag, i.e. 1σ. Examples of these "matches" are shown in Figure 2. Of course the present data are not sufficient for an independent period determination.

These criteria are rather severe, and we can miss candidates because of occasional larger errors on individual data points, in addition to the observational bias that causes us to miss the variables in those phase intervals where the light variation is modest. According to these criteria, we were able to derive a meaningful indication of variability for 2, 4, 11 and 8 such candidates in G11, G33, G64 and G322, respectively.

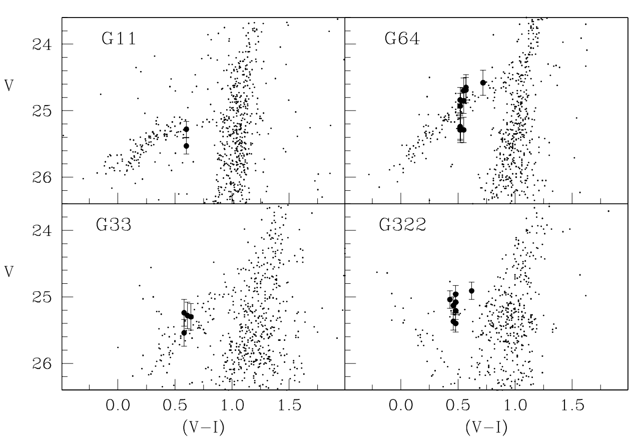

FIG. 3. Location of the candidate variable stars on the CM diagram of the four clusters G11, G64, G33 and G322. See text for details.

By relaxing somewhat the selection criteria (for example by accepting that the data points match the templates within a 2σ error-bar) we found evidence for larger numbers of RR Lyrae candidates of both ab and c type in each of the four clusters. In fact, an additional 14, 6, 15 and 4 candidate variables, whose classification is uncertain, are also present in G11, G33, G64 and G322, respectively.

All selected candidates are well within the tidal radii of the clusters ($\sim$ 16, 11, 12 and 10 arcsec in G11, G33, G64 and G322, respectively).

In Figure 3 we show the location of the candidate variables in the CMD's of their respective clusters. The mean V magnitudes and V–I colors of the variable candidates are those of the respective templates, after adding to the mean V magnitudes the same "vertical" shifts used in item iii) before.

The major sources of error in the $< V >$ thus estimated are: a) the uncertainty in the reddening (ΔE(B–V)= $\pm$20% leads to ΔV= $\pm$(0.06–0.14) mag); b) the intrinsic spread in the template $< V >$ (for our template stars ΔV $\leq$ 0.12 mag, however the intrinsic $< V >$ of the RR Lyraes in any globular cluster can span a rather large range, up to about 0.5 mag or more); and c) the photometric accuracy of the data points and consequent accuracy of the fit to the template, $\pm$0.10 mag. This leads us to estimate error-bars on the individual $< V >$ values of $\pm$ 0.12, 0.20, 0.19 and 0.13 mag for the candidate variable stars in G11, G33, G64 and G322, respectively.

Within these uncertainties, the agreement of the candidate RR Lyraes with their respective HBs is quite good, in particular it is significantly better than what is required by the original selection criteria, further supporting their identification.

4. DISCUSSION AND CONCLUSIONS

Using HST archival data, we have found 2, 4, 11, and 8 candidate RR Lyrae stars in the M31 globular clusters G11, G33, G64, and G322, respectively. The evidence for the RR Lyrae nature of some of these candidates is stronger than for others. Nonetheless, the fact that good RR Lyrae candidates could be identified from an archival dataset which is not ideal for this sort of variability search provides clear evidence that suitable HST observations can be used to identify RR Lyrae stars in M31 globular clusters. With additional HST data, it should be possible to determine periods, light curves, and pulsational properties for the cluster RR Lyrae.

The globular cluster G64 contains the largest number of candidate RR Lyrae stars, combined with a predominantly blue HB. This in itself is not surprising since, in the Milky Way, clusters such as M15 with predominantly blue HBs can have relatively large RR Lyrae populations. It is noteworthy, however, that the RR Lyrae candidates in G64 (as well as the related HB) are unusually bright compared to those in the other clusters, when corrected for a reddening of E(B-V) = 0.17. If the HB in G64 is not unusually bright, for example because of non-canonical phenomena such as high primordial helium abundance, mixing or rotation (Sweigart 1997), then G64 is significantly closer to us (by $\sim$ 100 kpc) than the main body of M31, or its reddening has been overestimated by about 0.10 mag.

Assuming $(m-M)_0$=24.43 for M31 (Freedman and Madore 1990), we note that the absolute magnitude of the RR Lyrae candidates turns out to be generally rather "bright", hence in better agreement with the “long” distance scale. However, this indication is very tentative and preliminary and needs more data and further study for confirmation.

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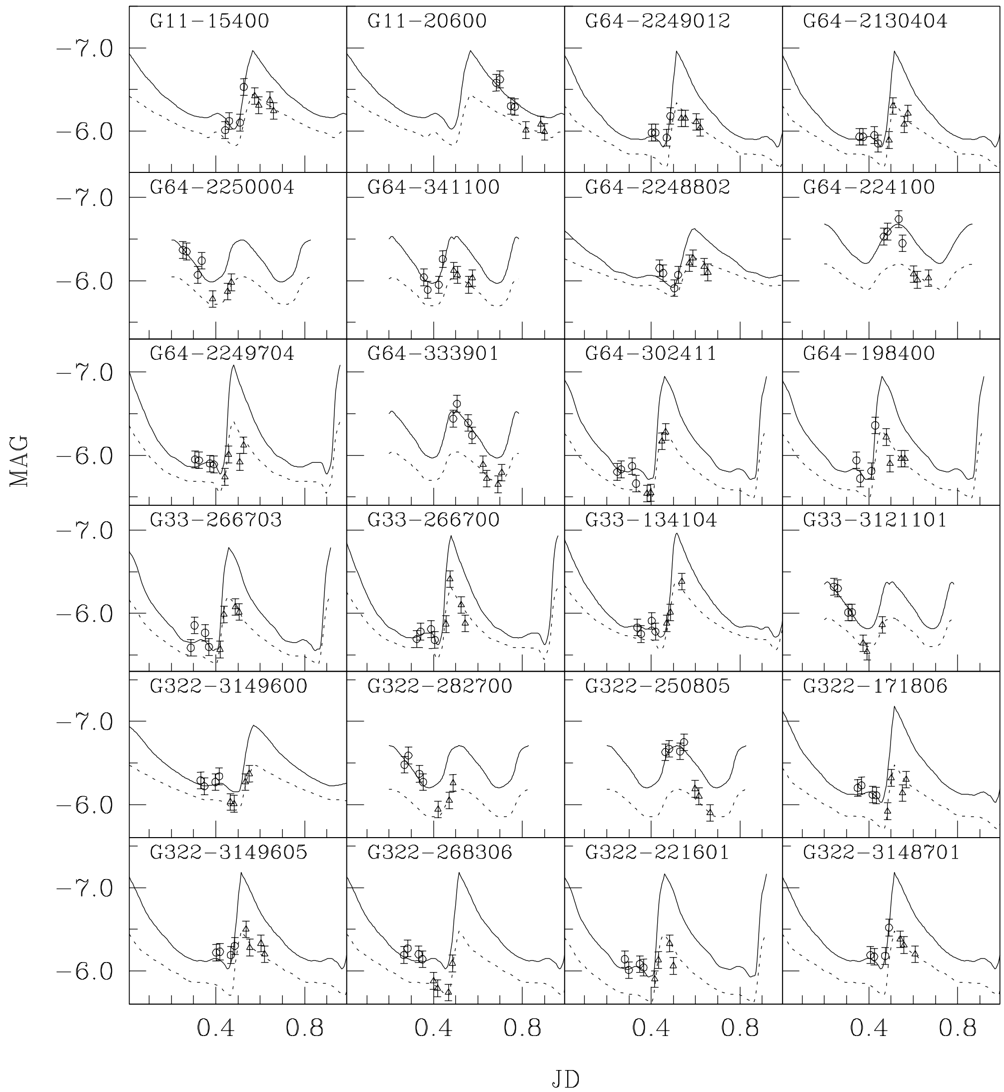

FIG. 2.— Examples of HST V (circles) and I (triangles) data fitting to RR Lyrae template V (solid lines) and I (dotted lines) light curves. The vertical scale is magnitudes with an arbitrary zero-point, but the relative V and I magnitudes, both for the template light curves and for the observed data sets, are the real ones. The horizontal scale is Julian Days, and the templates have been arbitrarily shifted in order to show the maximum light variation near the center of the frame.